EUV Workshop 2013

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JSR Micro

MATERIALS INNOVATION

JSR

EUV Resist Materials and Process for 16 nm Half Pitch and Beyond

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- ***16 nm LS and sub 20nm CH patterning with new materials and process***
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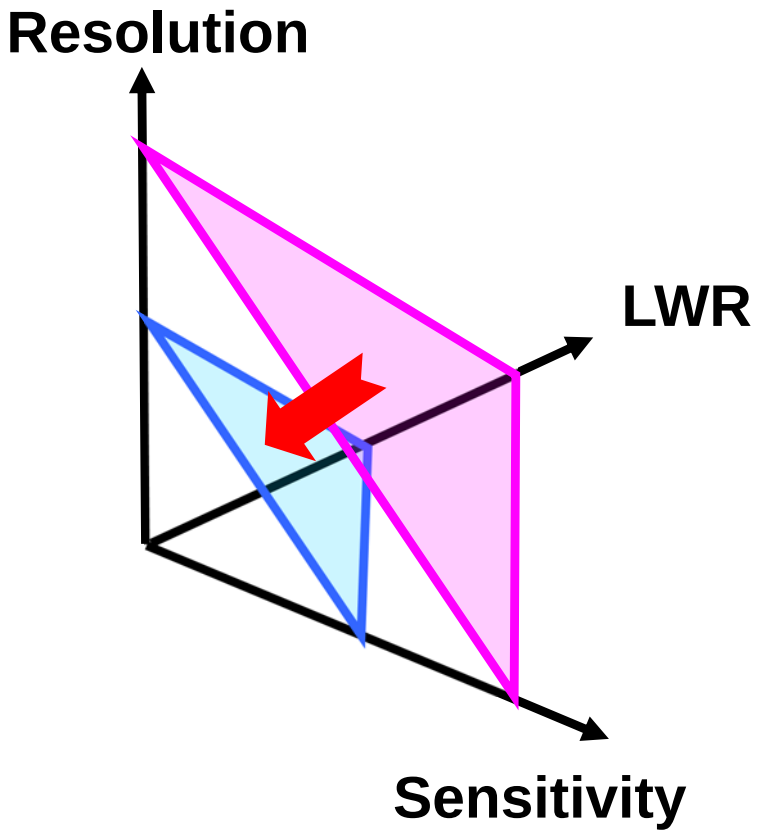
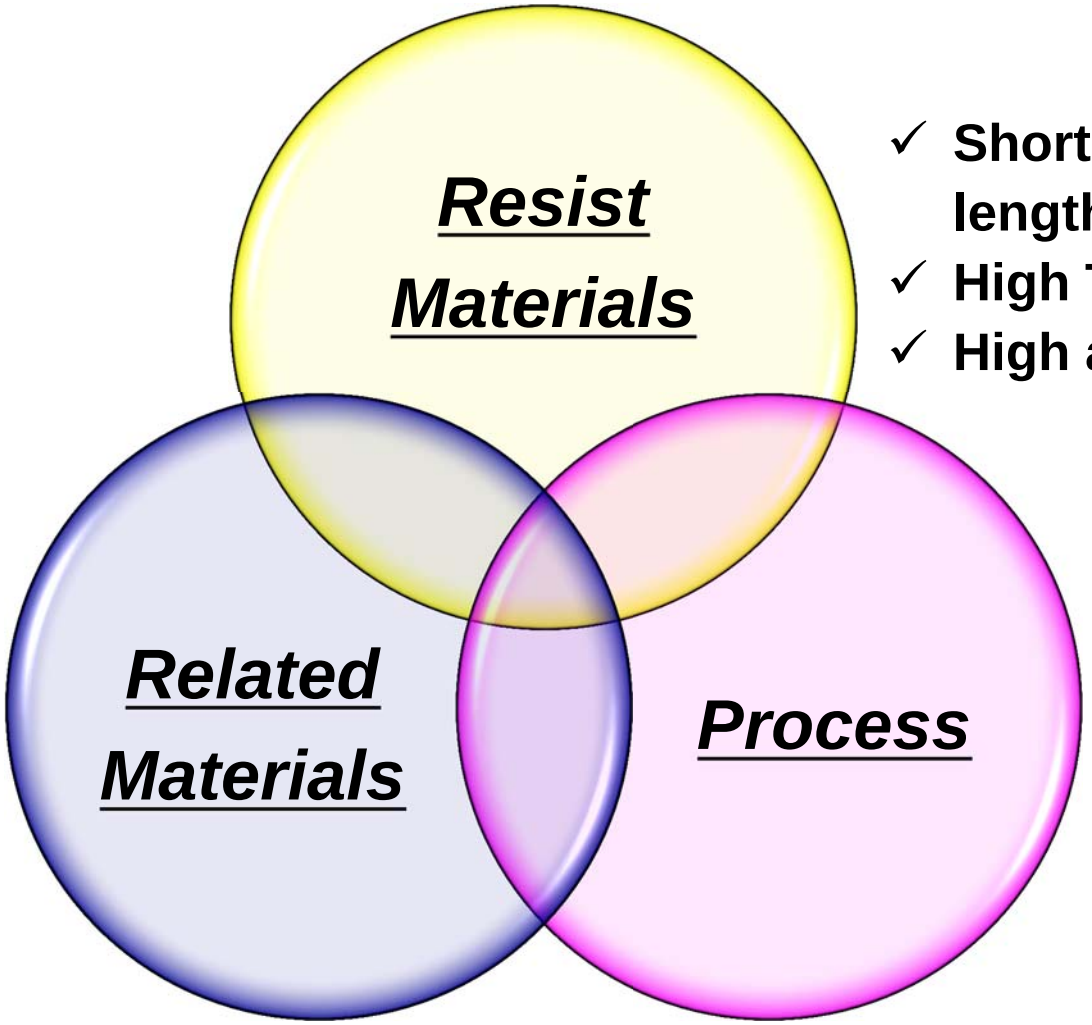
Challenge for EUV Resist



✓ *Low Outgassing*
✓ *Suppression of OOB influence*

- ***Simultaneous improvement in Resolution, LWR and Sensitivity (RLS) is required***
- ***EUV resist must have low outgassing characteristics as well as suppression of OOB influence***

JSR Approach for EUV Resist Performance Improvement



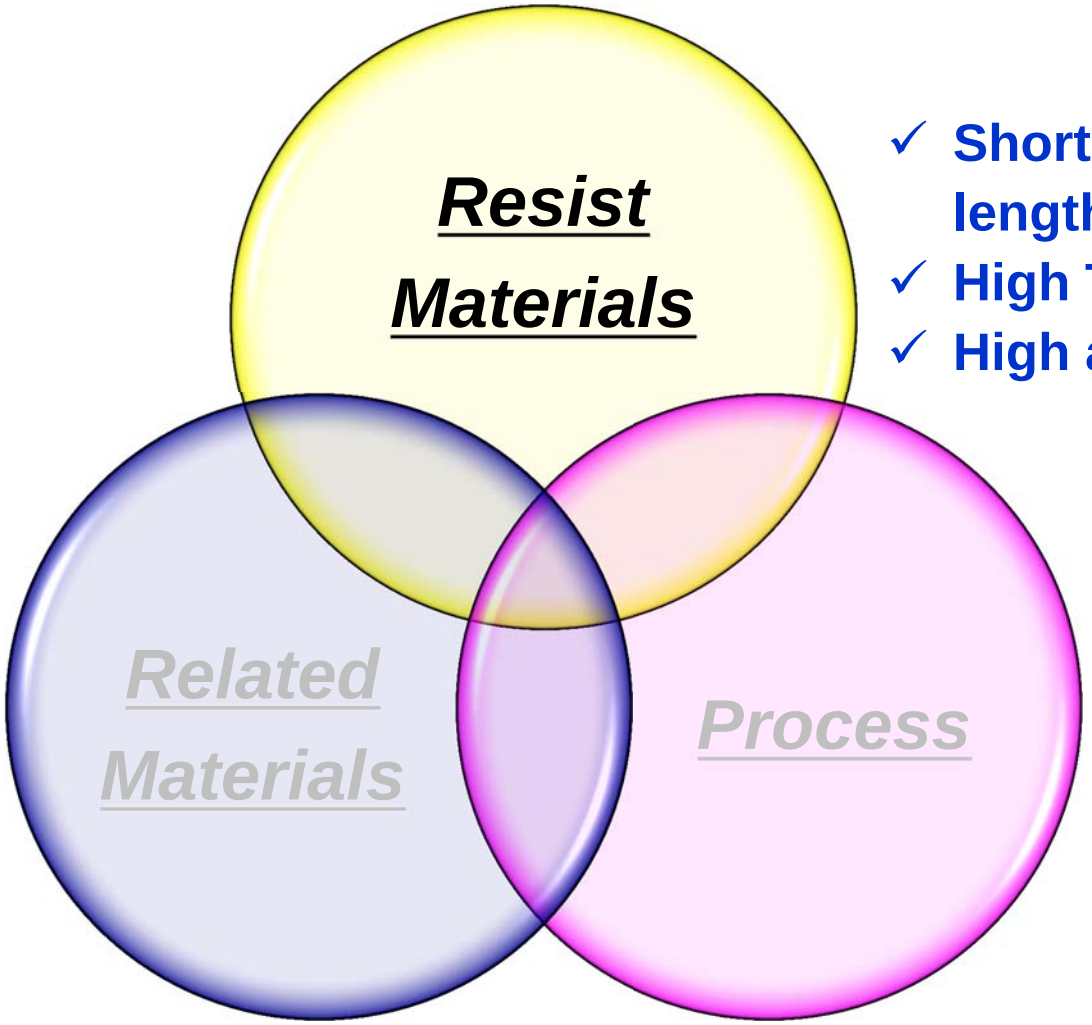
- ✓ Short acid diffusion length PAG
- ✓ High Tg resin
- ✓ High absorption resin

- ✓ Under-layer
- ✓ Top-coat

- ✓ Rinse agent
- ✓ DSA

➢ ***EUV Resist RLS improvement with combination of materials and process***

EUV Resist Performance Improvement
1. Resist Materials



- ✓ Short acid diffusion length PAG
- ✓ High Tg resin
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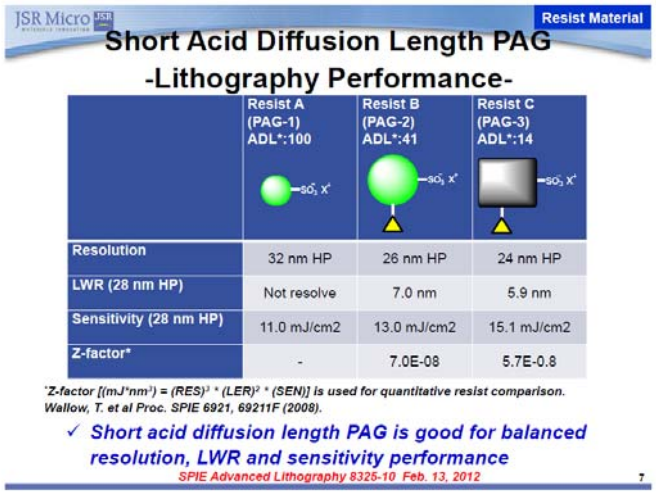
- ✓ Under-layer
- ✓ Top-coat

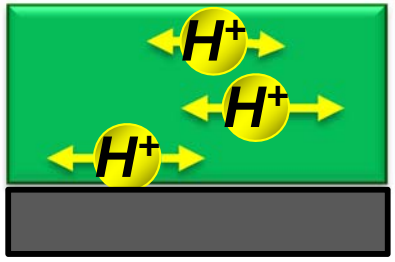
- ✓ Rinse agent
- ✓ DSA

RLS Improvement: Resist Materials

Short acid diffusion length PAG	High Tg resin	High absorption resin
Acid diffusion control	Acid diffusion control	High acid yield
LWR & Resolution	LWR & Resolution	Sensitivity



High Tg material
→Short acid diffusion length



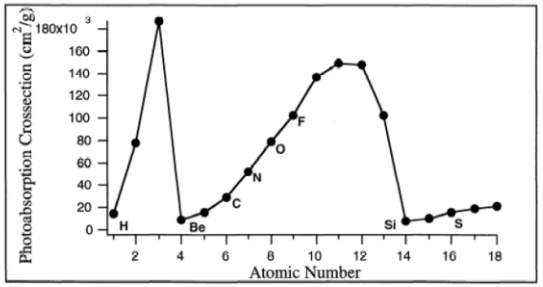
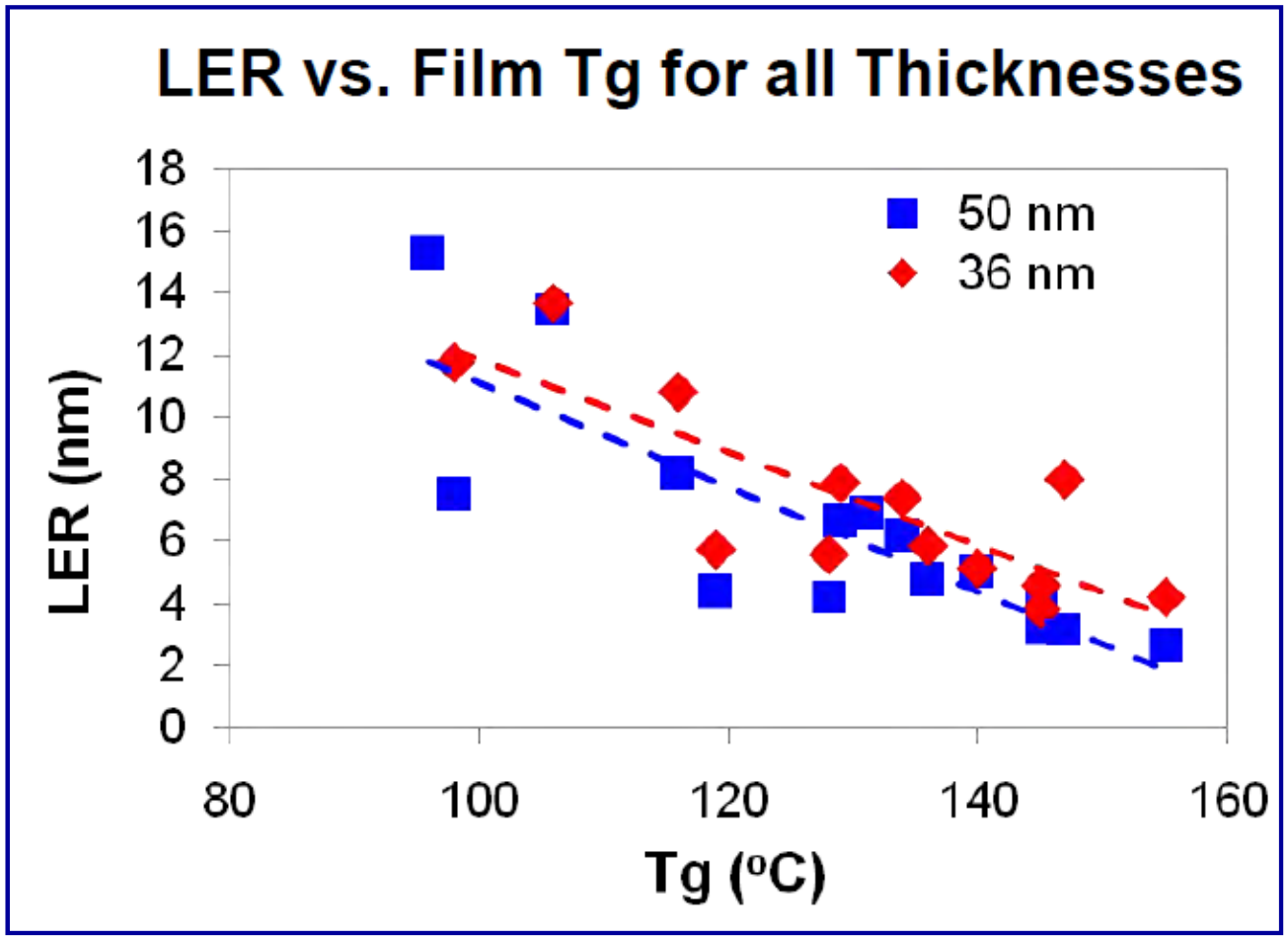


Figure 1: Elemental absorption cross-sections at 13.4 nm wavelength. Elements commonly found in photoresist materials are H, C, N, O, F, and S.

P. Dentinger et al.
SPIE 3997 (2000) 588.

- ***Improvement of RLS performance of resist with short acid diffusion length PAG was demonstrated***
- ***Effect of resin glass transition temperature (Tg) and absorption was investigated in details***

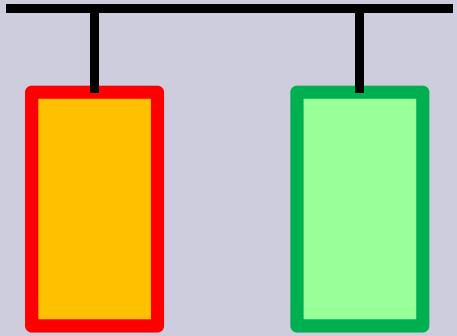
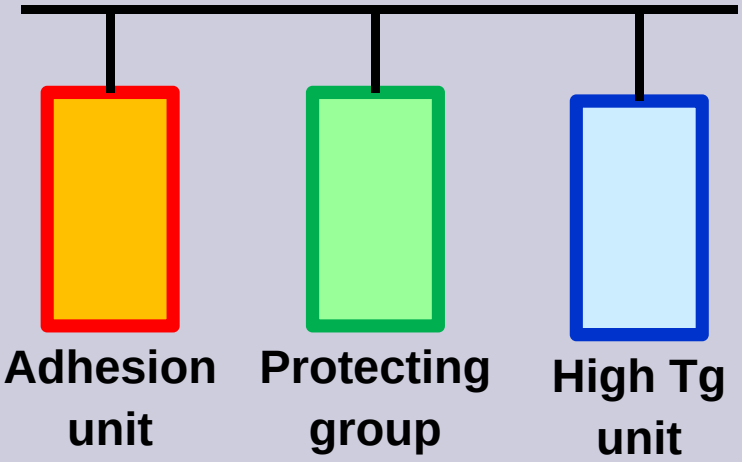
Effect of Tg on LER



Brian Cardineau et al. 2011 International Symposium on EUVL

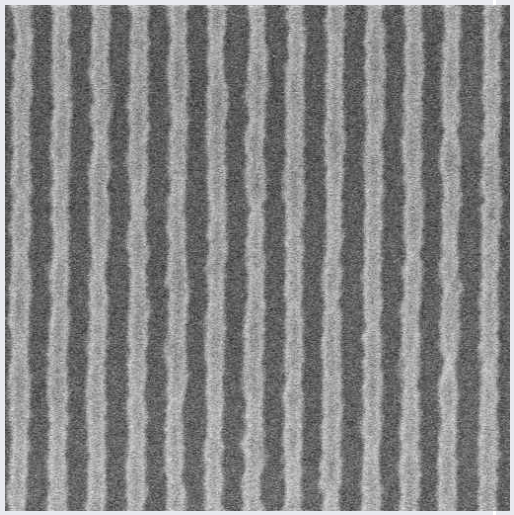
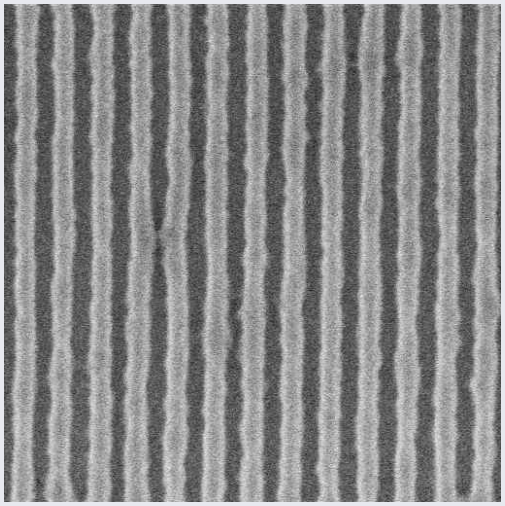
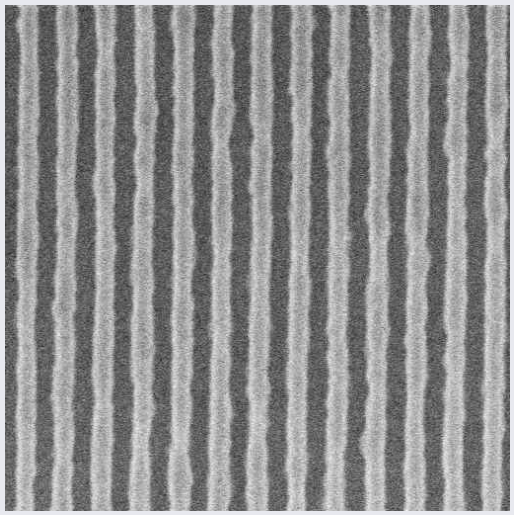
- ***JSR developed resin with higher Tg to understand the effect on LWR***

Development of High Tg Resin

	Std. resin	High Tg resin
Resin Composition		
Tg (°C)	Std.	Std. + 20
Acid diffusion length (ADL, Relative Value)	100	60

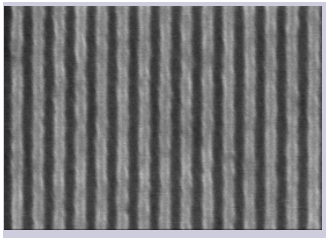
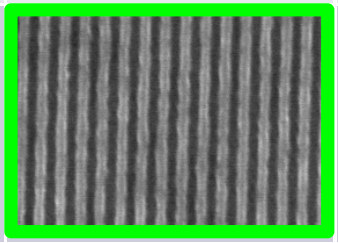
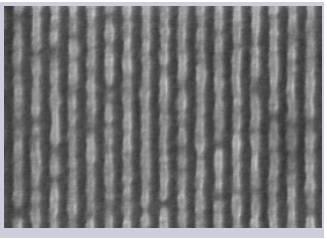
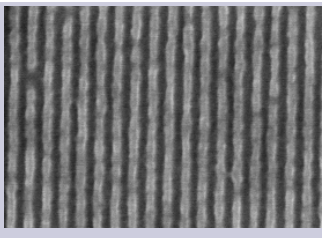
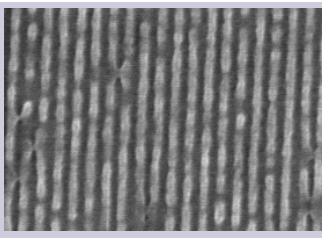
- ***High Tg EUV resin was prepared by introduction of high Tg monomer unit into standard resin***
  - ***Tg increased by 20 ℃ by adding high Tg monomer to std. resin***
  - ***ADL become short by 40% by applying high Tg resin***

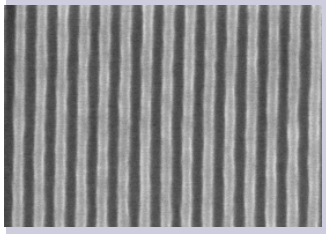
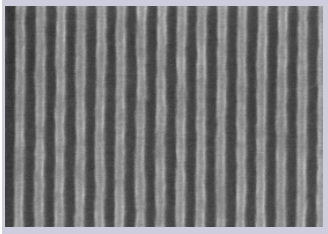
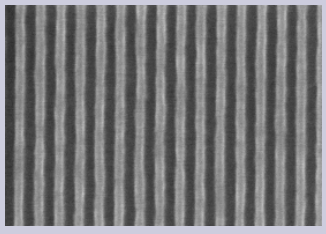
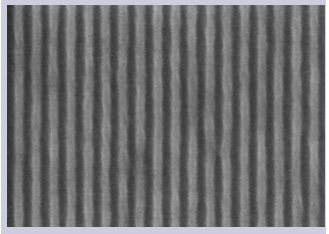
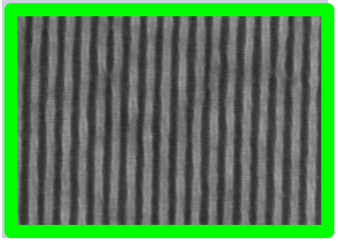
Resin Tg Impact on LWR

Resist	Resist A	Resist B	Resist B
Resin	Std	High Tg resin	High Tg resin
PEB	Std	Std	High
Sensitivity	16.7 mJ/cm^2	18.6 mJ/cm^2	15.4 mJ/cm^2
LWR	6.2 nm	4.6 nm	5.0 nm
Z-factor	5.68E-08	3.56E-08	3.32E-08
26 nm hp			

- ***Resist with high Tg resin shows good LWR and Z-factor than std resist***
- ***Combination of high Tg resin and high PEB improved RLS performance***

Resin Tg Impact on Resolution

	HP	22 nm HP	20 nm HP	19 nm HP	18 nm HP	17 nm HP
Std. resin	Sen.	37.0 mJ/cm^2	37.0 mJ/cm^2	39.6 mJ/cm^2	39.6 mJ/cm^2	42.2 mJ/cm^2
	LWR	4.3 nm	4.9 nm	-	-	-
	Image					

	HP	22 nm HP	20 nm HP	19 nm HP	18 nm HP	17 nm HP
High Tg resin (Quencher Optimization)	Sen.	31.8 mJ/cm^2	34.4 mJ/cm^2	34.4 mJ/cm^2	34.4 mJ/cm^2	37.0 mJ/cm^2
	LWR	3.2 nm	3.2 nm	3.6 nm	4.3 nm	4.1 nm
	Image					

➢ ***Resist with high Tg resin shows good resolution***

Development of High Absorption Resin

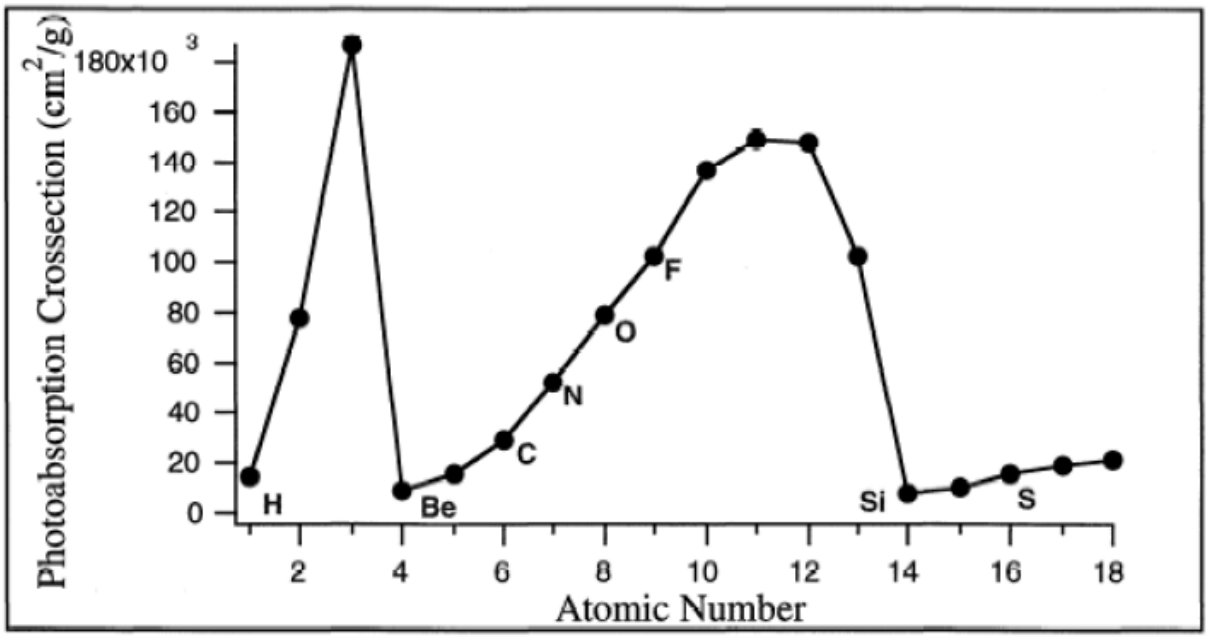
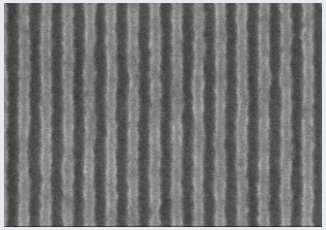
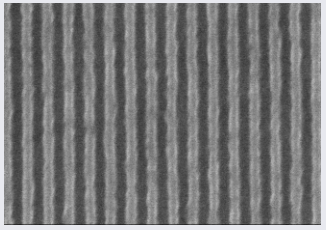
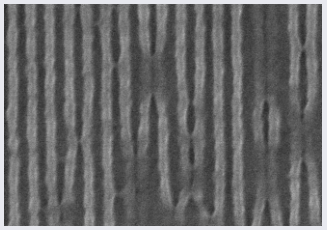


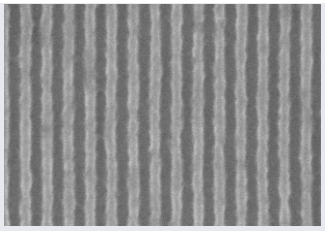
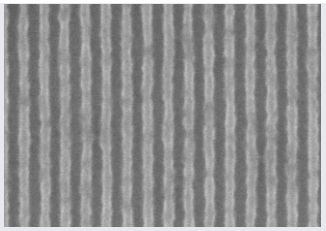
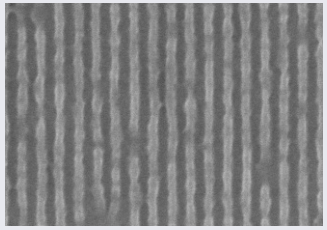
Figure 1: Elemental absorption cross-sections at 13.4 nm wavelength. Elements commonly found in photoresist materials are H, C, N, O, F, and S.

P. Dentinger et al. SPIE 3997, 588 (2000)

- ***Resin including high absorption element was developed for resist sensitivity improvement***

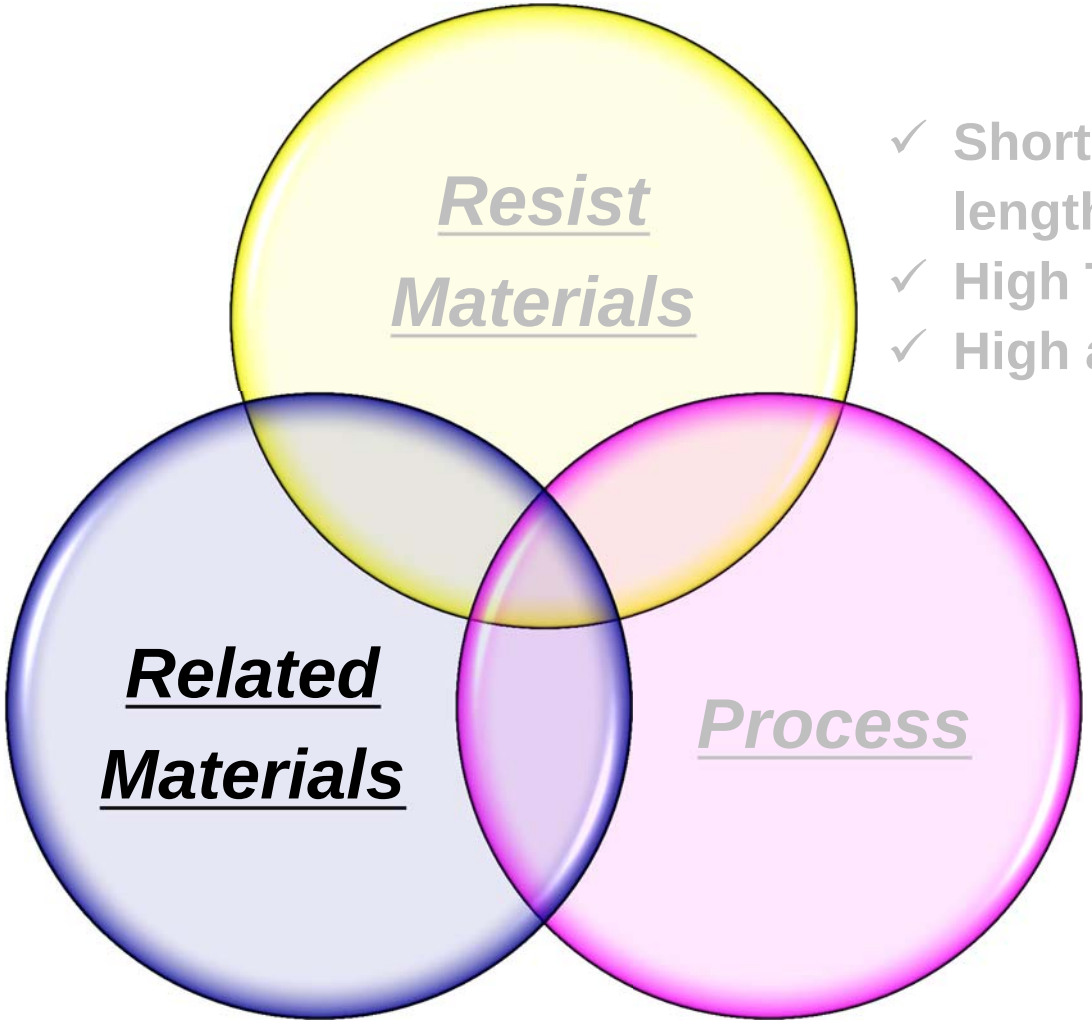
Absorption Impact on Sensitivity

	HP	22 nm HP	20 nm HP	19 nm HP
EUV Resist with Std Resin	Sensitivity	17.2mJ/cm^2	17.2mJ/cm^2	17.2mJ/cm^2
	LWR	5.8nm	5.5nm	-
	Image			

	HP	22 nm HP	20 nm HP	19 nm HP
EUV Resist with High absorption resin	Sensitivity	15.0mJ/cm^2	15.0mJ/cm^2	15.0mJ/cm^2
	LWR	5.5nm	5.8nm	-
	Image			

- ***Sensitivity improved by 15 % with high absorption resin***

EUV Resist Performance Improvement
2. EUV lithography related materials

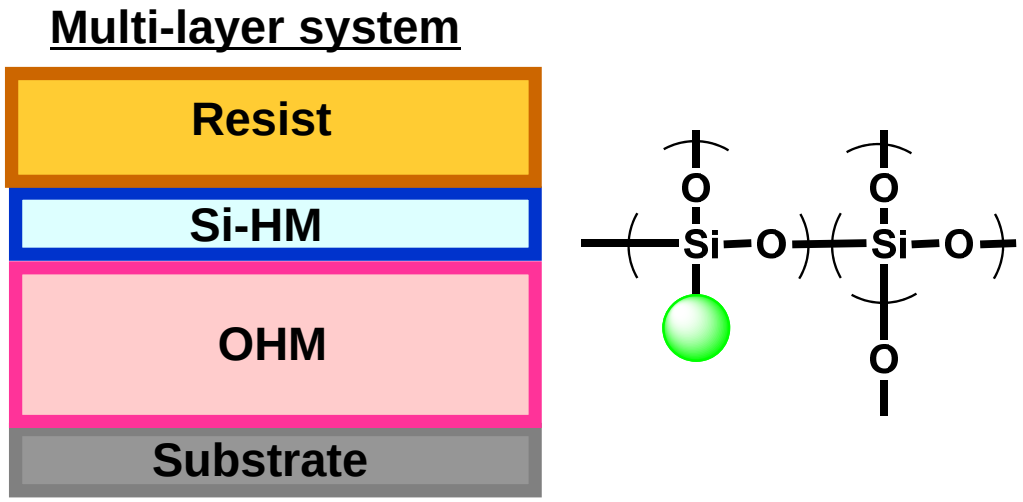


- ✓ Short acid diffusion length PAG
- ✓ High Tg resin
- ✓ High absorption resin

- ✓ Under-layer
- ✓ Top-coat

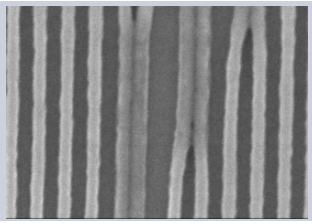
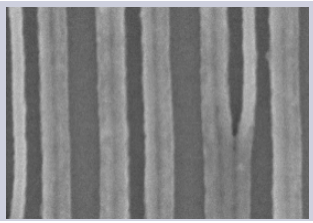
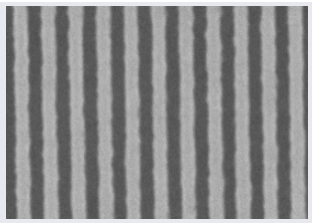
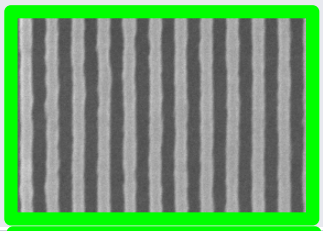
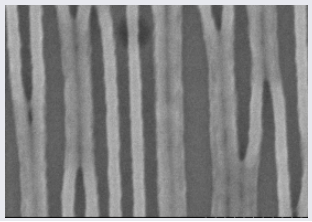
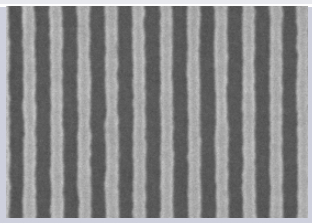
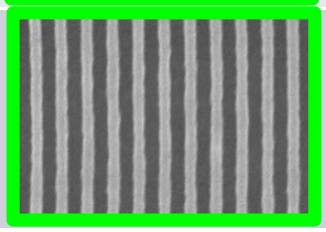
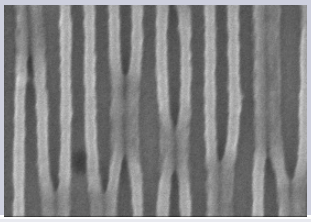
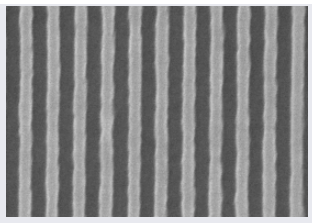
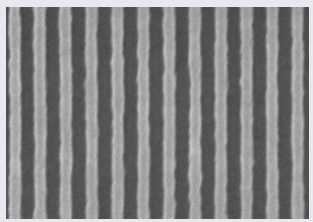
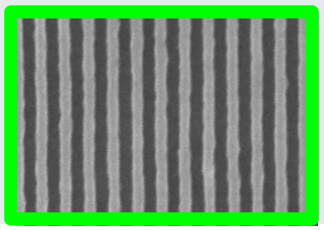
- ✓ Rinse agent
- ✓ DSA

Development of Under Layer (UL) – Si-HM



- ✓ *Si-HMs with different composition were evaluated to understand the effect of Si-HM composition on resist pattern line collapse*
- ✓ *Resist sensitivity on organic UL and Si-HM was studied*

Si-HM Impact on Resolution

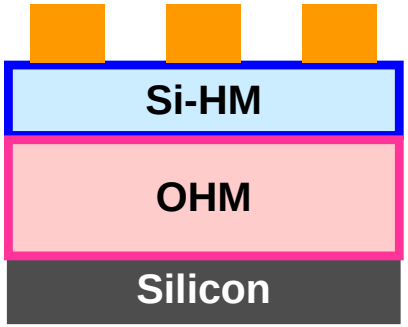
Si-HM	30 nm HP	28 nm HP	26 nm HP
Si-HM-A Contact angle :100 (relative value)			
Si-HM-B Contact angle :104 (relative value)			
Si-HM-C Contact angle :106 (relative value)			
Si-HM-D Contact angle :109 (relative value)			

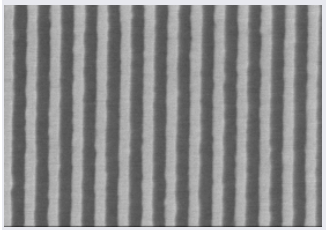
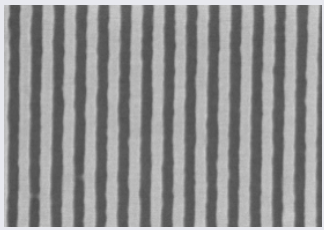
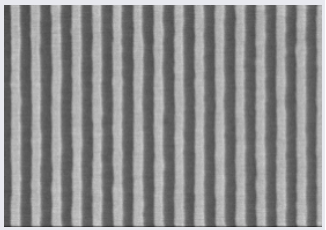
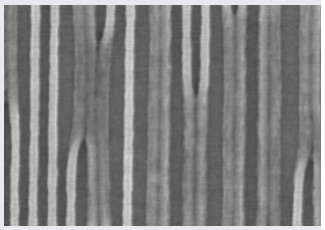
Exp. NA 0.30, Dipole

- ***Higher contact angle of Si-HM improves resist pattern collapse***
- ***Surface property is the key factor for improvement of pattern collapse***

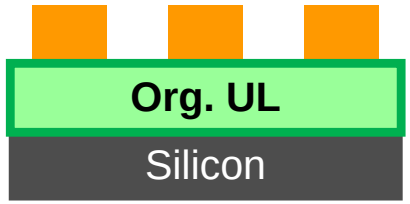
Si-HM impact on Sensitivity

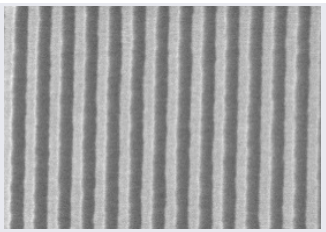
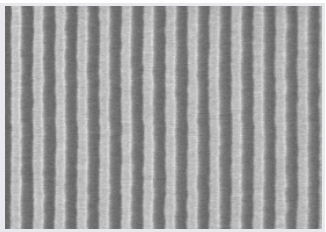
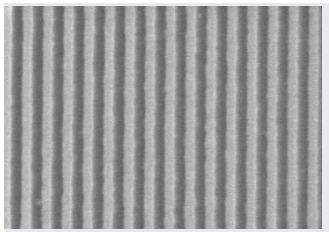
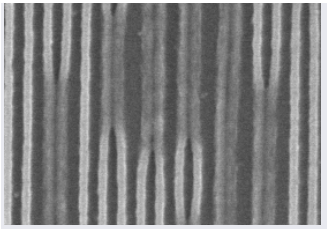
EUV resist



HP	32 nm HP	30 nm HP	28 nm HP	26 nm HP
Sensitivity	16.0mJ/cm^2	16.0mJ/cm^2	16.0mJ/cm^2	16.0mJ/cm^2
LWR	4.1nm	3.7nm	4.3nm	-
Image				

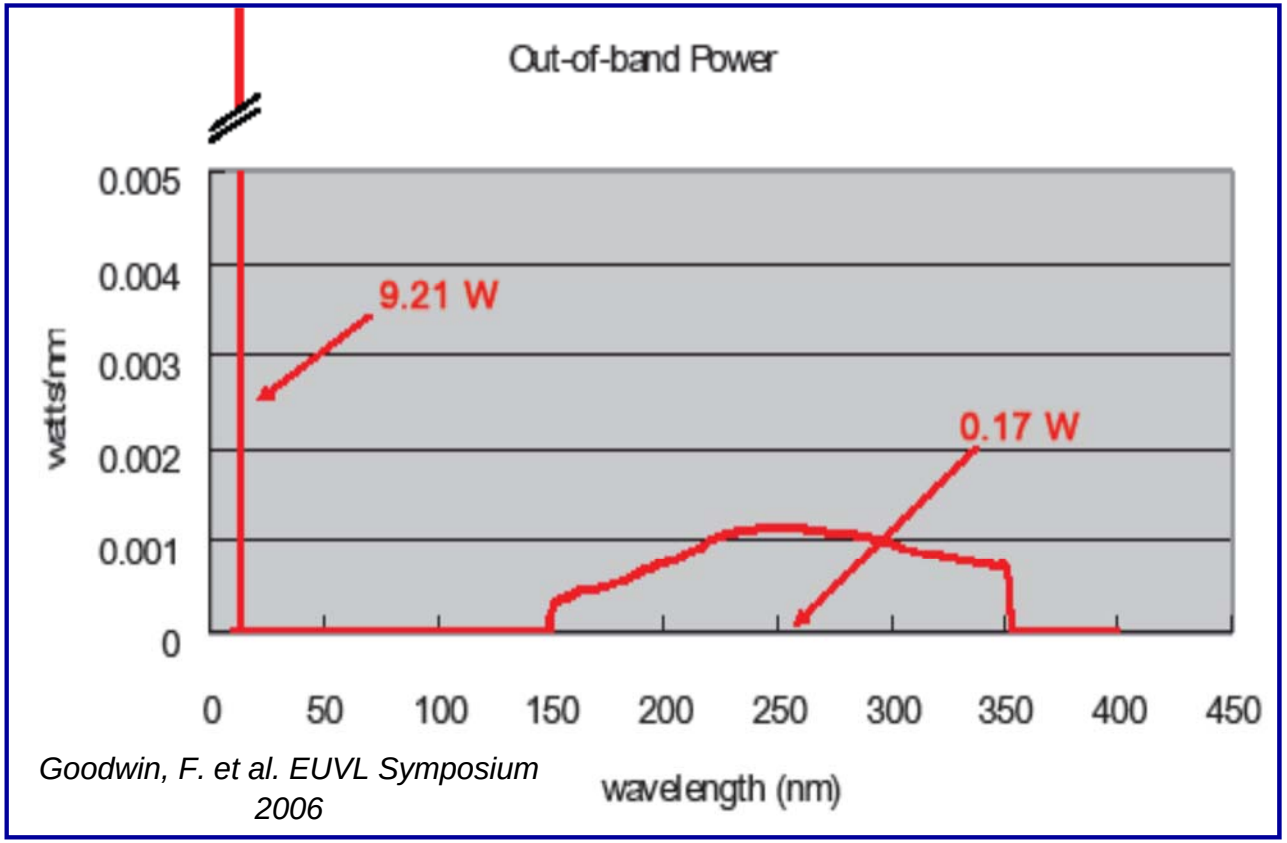
EUV resist



HP	32 nm HP	30 nm HP	28 nm HP	26 nm HP
Sensitivity	18.4mJ/cm^2	18.4mJ/cm^2	18.4mJ/cm^2	18.4mJ/cm^2
LWR	4.0nm	4.0nm	3.6nm	-
Image				

➢ ***Sensitivity improved by 15 % with Si-HM.***

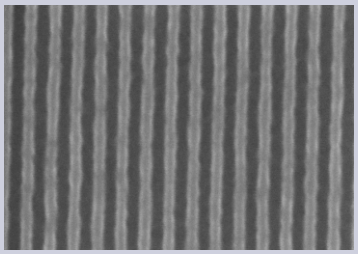
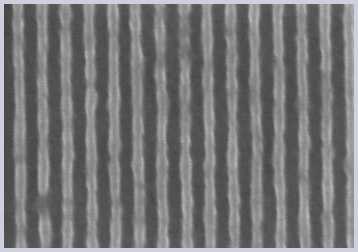
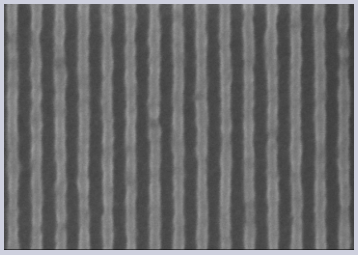
Development of EUV Topcoat: EUV Filter Coating (EFC)



Goodwin, F. et al. EUVL Symposium 2006

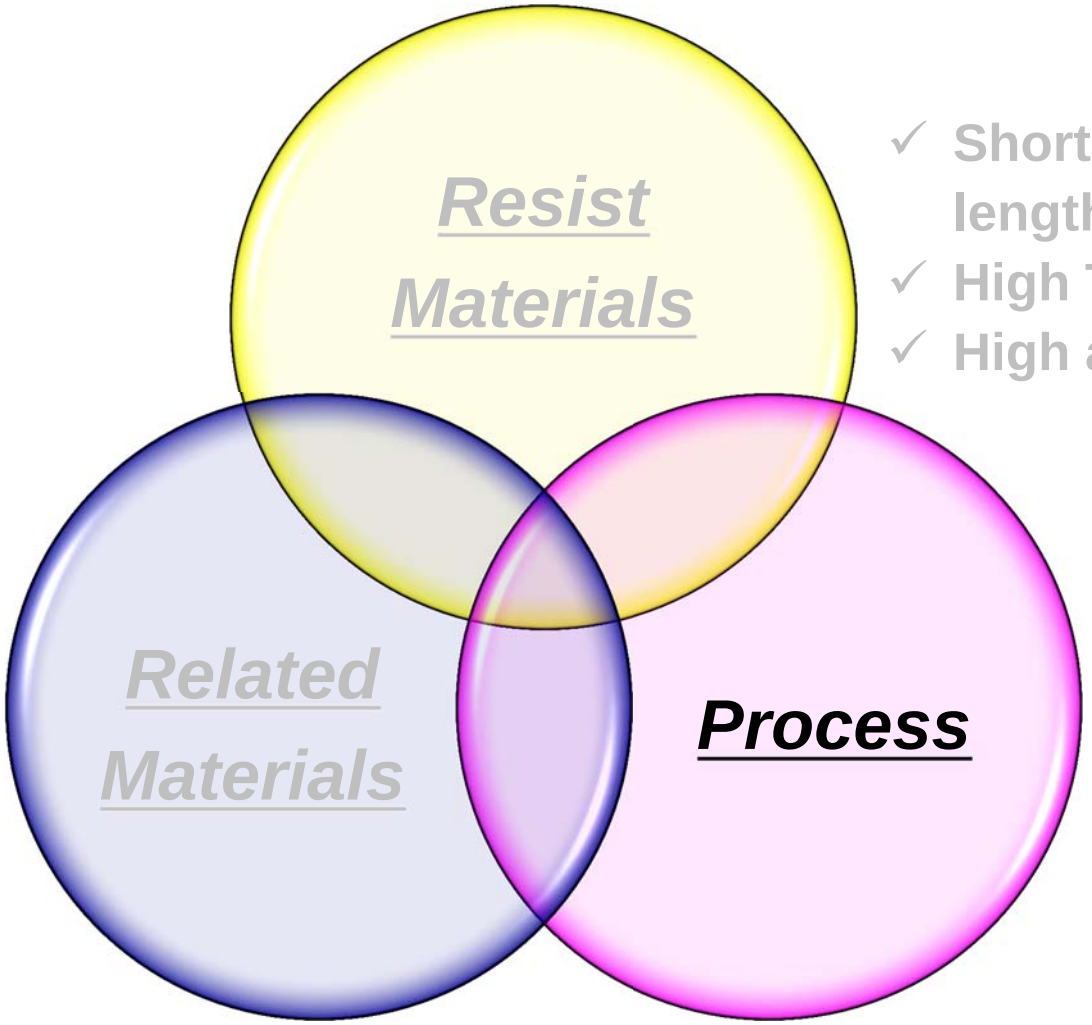
- ***Out-of-Band (OOB) radiation is concern for EUV lithography***
- ***OOB may degrade LWR and Resolution***
- ***EFC was developed and investigated for suppression of OOB***

Suppression of OOB with EUV Topcoat(EFC)

Stack	EUV resist / Org. UL / Silicon	EUV resist / Org. UL / Silicon	EFC / EUV resist / Org. UL / Silicon
Pseudo-OOB* [2.2mJ/cm² (Around 193nm broadband)]	EUV	EUV + OOB	EUV + OOB
22nmLS image			
Sensitivity (mJ/cm²)	22.0	17.4	25.1
LWR(nm)	4.6	6.8	5.0

- ***LWR degradation was observed with Pseudo-OOB irradiation***
- ***EFC showed suppression of OOB radiation Influence***

EUV Resist Performance Improvement
3. Process



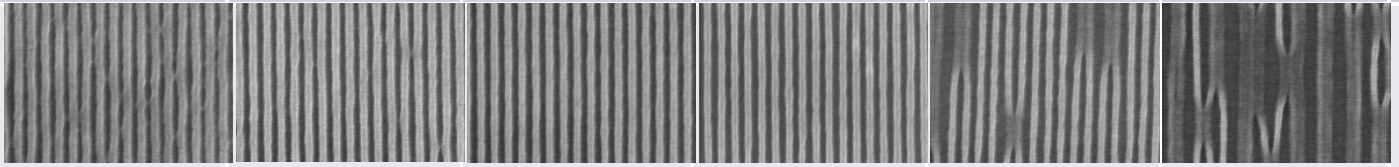
- ✓ Short acid diffusion length PAG
- ✓ High Tg resin
- ✓ High absorption resin

- ✓ Under-layer
- ✓ Top-coat

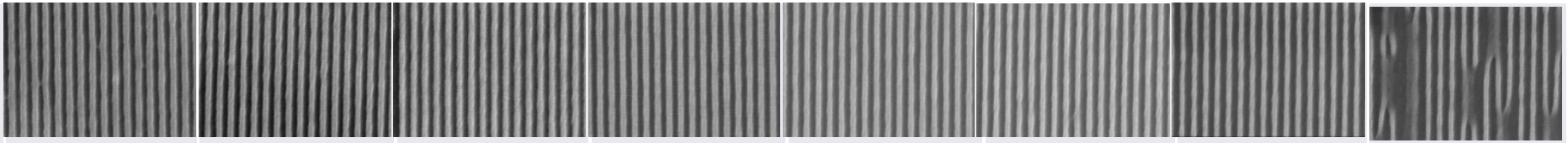
- ✓ Rinse agent
- ✓ DSA

FIRM™ Rinse* Process Impact for Pattern Collapse

Without FIRM™ rinse

Dose (mJ/cm²)	28.9	30.7	34.2	36.0	37.8	39.5		
CD(nm)		22.2	20.9	19.8	-	-	-	-
20 nm HP								

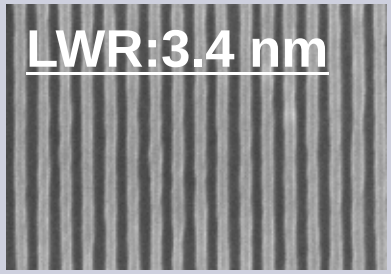
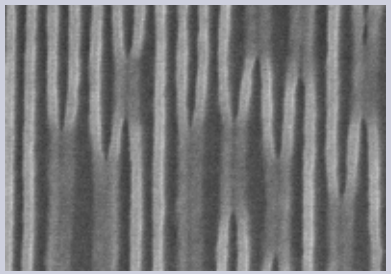
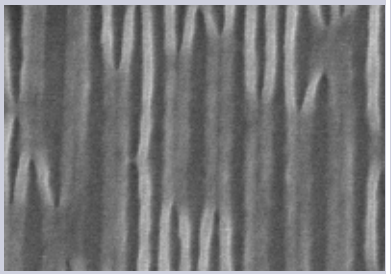
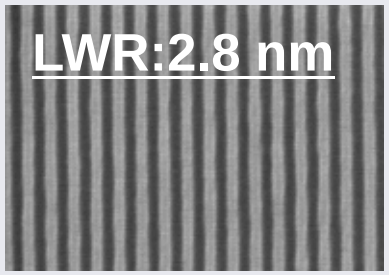
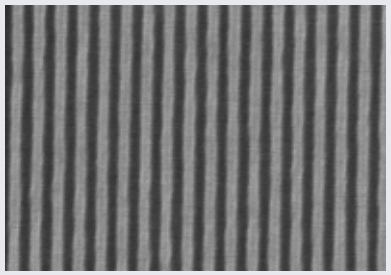
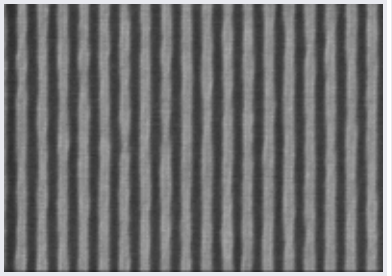
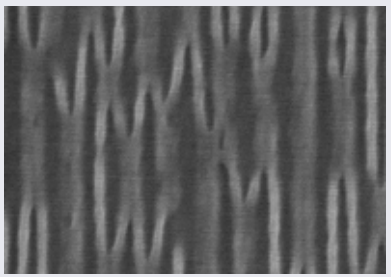
With FIRM™ rinse

Dose (mJ/cm²)	28.9	30.7	34.2	36.0	37.8	39.5	41.3	43.1
CD(nm)	21.5	20.9	20.1	20.0	19.0	18.3	16.8	-
20 nm HP								

*FIRM™ Extreme™ 12

➢ *FIRM™ rinse process improves pattern collapse margin*

FIRM™ Rinse*Process Impact for Resolution and LWR

HP	20 nm HP	19 nm HP	18 nm HP	17 nm HP
Without FIRM™ Rinse				
With FIRM™ Rinse				

*FIRM™ Extreme™ 12

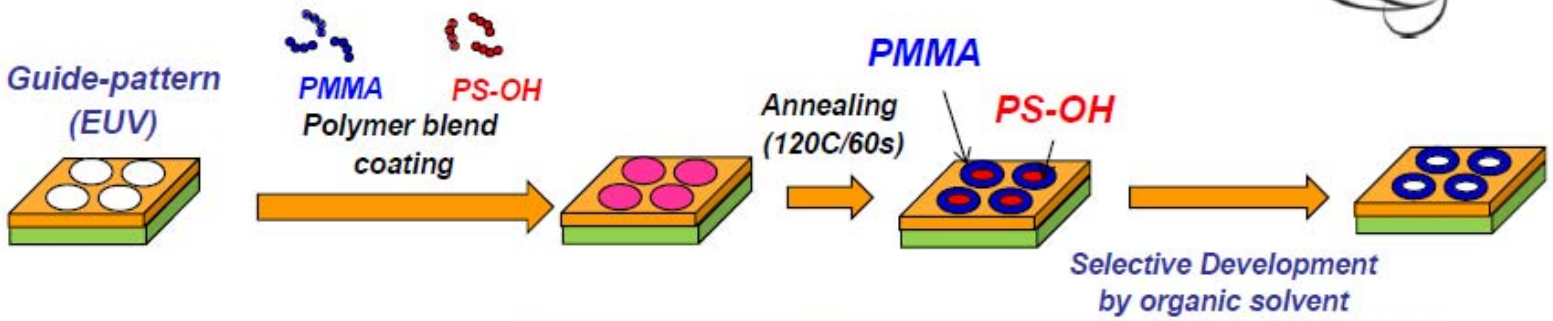
- *Higher resolution (sub 20 nm) observed with rinse process*
- *LWR improved by 15 % with rinse process*

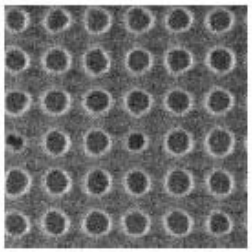
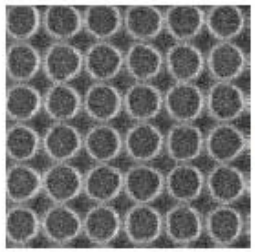
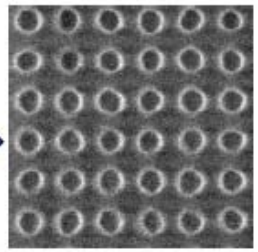
With DSA

JSR SEMICONDUCTOR MATERIALS LABORATORY JSR

Combination of EUV and DSA

imec



	EUV Only	EUV Only	EUV+DSA
SEM Image			
Dose (mJ/cm^2)	23.0	15.0	15.0
CD (nm)	39.9	56.6	35.6
Shrink Amount	-	-	21.0
Local CDU (3σ, nm)	2.2	3.53	2.2

✓ *Combination of EUV and DSA improved the relation of sensitivity and CDU.*

19th Annual SOKUDO Lithography Breakfast Forum

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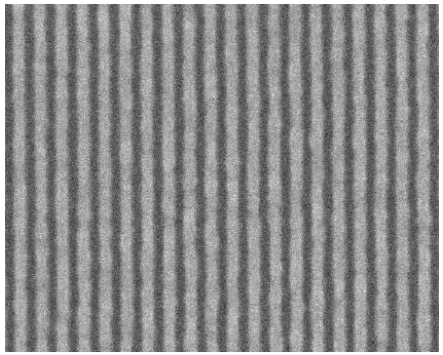
Contents

- *Challenge for EUV Resist & JSR approaches*
- *EUV Resist Resolution, LWR and Sensitivity improvement*
  - *Resist materials development*
  - *EUV lithography related materials effect*
  - *Evaluation of process effect*
- ***16 nm LS and sub 20nm CH patterning with new materials and process***
- *Summary*

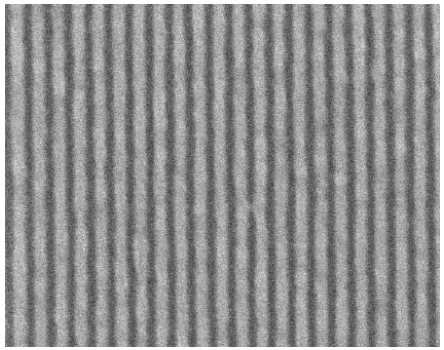
16nm LS & sub 20nm CH Patterning with New Materials & Process

LS Ultimate resolution

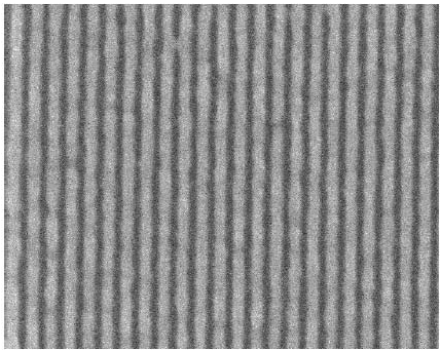
16nm HP



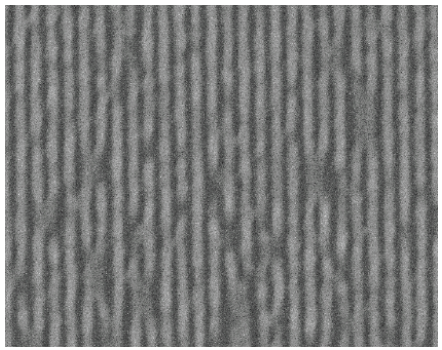
15nm HP



14nm HP



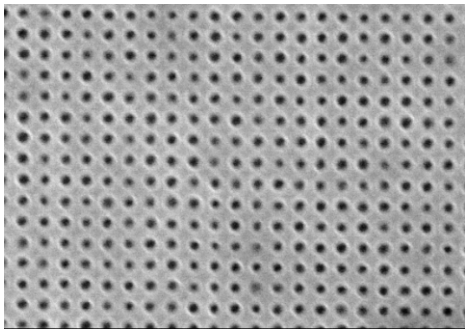
12nm HP



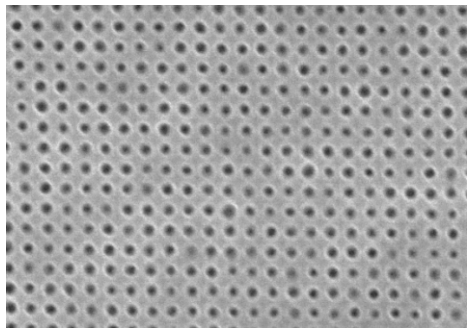
Exposure tool: EUV interferometer at PSI

CH Ultimate resolution

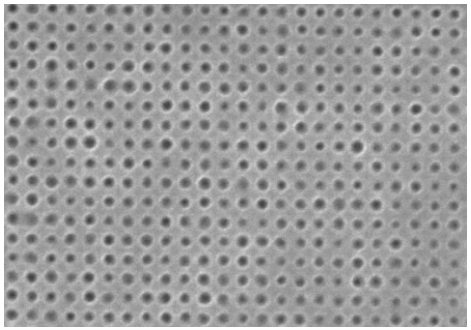
20nm HP



19nm HP



18nm HP

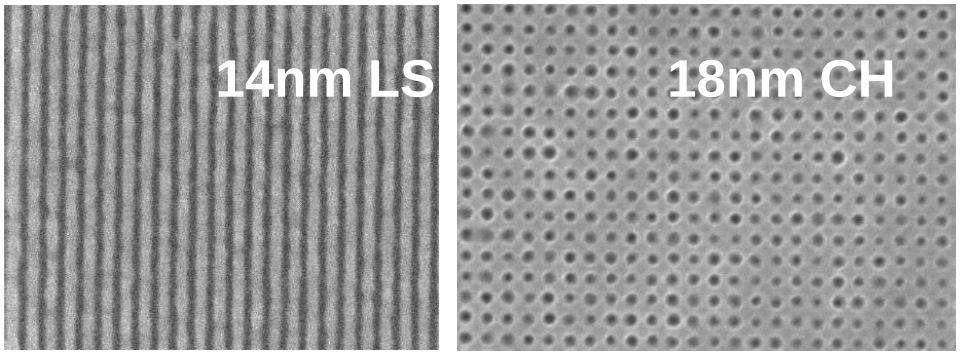


Exposure tool: Berkeley MET

- ***JSR EUV resist has the potential to achieve of 14 nm LS and 18 nm CH patterns***

Summary

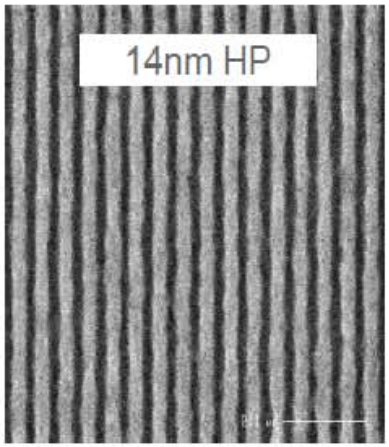
- ✓ ***Material & process development for performance improvement***
  - ***High Tg or high absorption resin shows good balance between LWR and sensitivity***
  - ***Si-HM UL improves resolution and sensitivity***
  - ***Topcoat shows suppression of OOB radiation influence***
  - ***Rinse agent improves resolution and LWR***
  - ***DSA can provide better process (sensitivity, CDU)***
- ✓ ***Combination of material and process***
  - ***JSR EUV resist achieved 14 nm LS and 18 nm CH resolution***

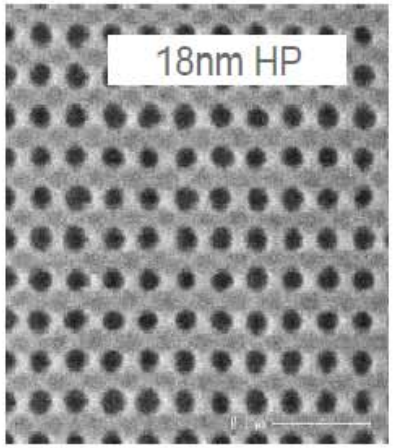


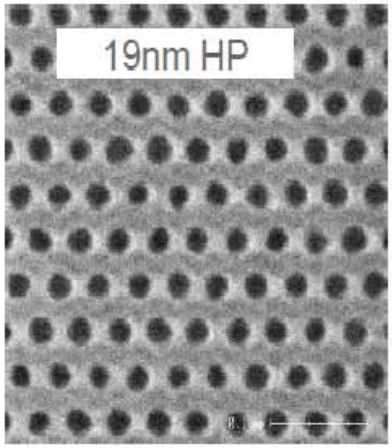
JSR resist on NXE:3300B

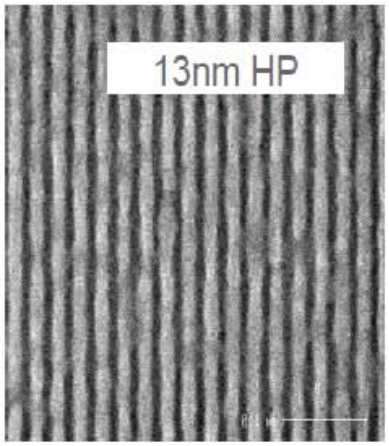
Resolution shown on NXE:3300B for dense line spaces, regular and staggered contact holes; all single exposures

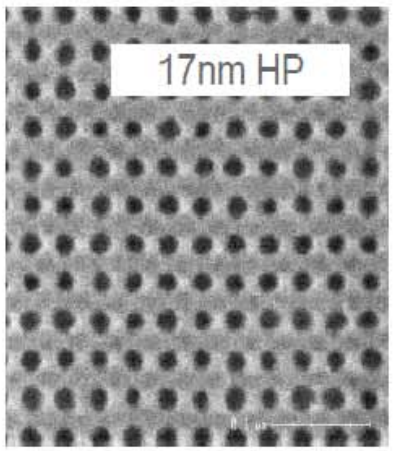
ASML

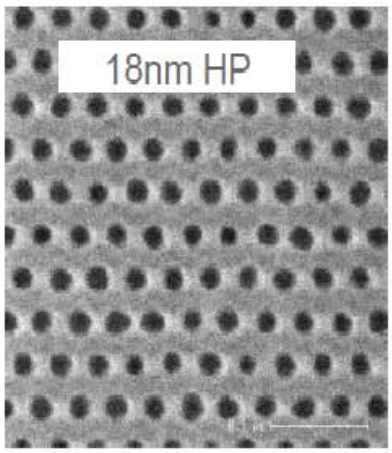








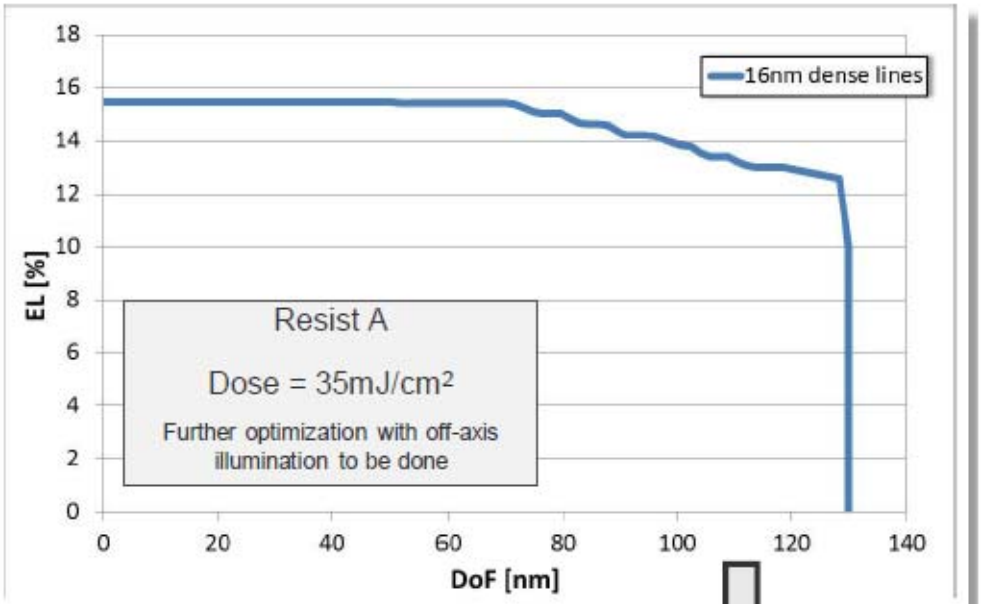


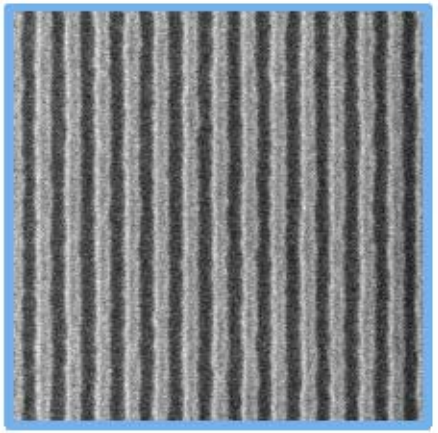


JSR resist 16nm performance on NXE:3300B

16nm dense lines with >15% exposure latitude and >120nm DoF on NXE:3300B (dipole-45 setting)

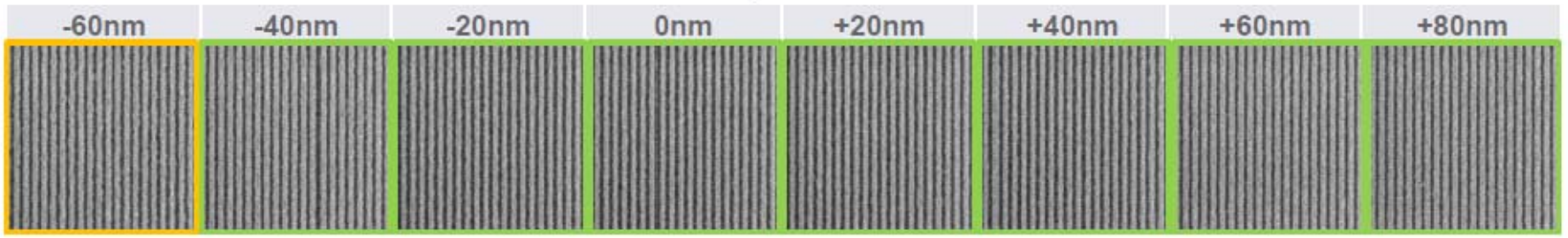
ASML





16nm L/S Dipole 45X
29.0mJ/cm2
Resist B

imec



Acknowledgment

The author gratefully thanks to PSI (Dr. Yasin Ekinci), SEMATECH, and IMEC for the close collaboration as well as to ASML for NXE3300 data.

Thank you for your attention !!

Materials Innovation

JSR

With chemistry, we can.